CHAPTER 4

INSTALLATION AND TESTING OF UNINTERRUPTIBLE POWER SUPPLY (UPS) SYSTEMS

4-1. Construction and installation of static UPS systems

The construction and installation of the UPS are critical to its proper operation.

a. Construction features of static systems. There are several construction features about the UPS that contribute to the system as a whole.

(1) Charger/inverter. In addition to the basic components of the charger/inverter, an input transformer is normally connected at the charger for isolating the charger components from the power source. Also, surge suppression devices are used at the input to protect the charger components from high transient voltages. Various protective and control devices may be used on static UPS systems including a thermal magnetic circuit breaker at the system alternating current (ac) inputs (with indicating lights to indicate the breaker open/close position), devices to detect and alarm loss of ac input, and devices to detect and alarm low/high charger output direct current (dc) voltage. The power and control components are normally mounted in one or more free standing, sheet metal cabinets. One cabinet may be adequate for smaller systems. The cabinets are normally designed for front access. All components can be inspected or removed from the front of the cabinet by opening a hinged door. Meters, indicating lights, control switches or pushbuttons, and adjustment potentiometers may be located inside the cabinet or mounted on the hinged door. A static UPS with a power range of 150 to 750 kVA is shown in figure 4-1. Electronic control components are normally assembled in a modular construction with drawout removable modules. The cabinet doors are provided with screened filtered openings for cooling. Cooling may be either by natural convection or by fans. Fans are typically used in larger systems. The cabinets are normally designed to allow power and control cables to enter from either the top or bottom.

(2) Batteries and racks for smaller systems. Batteries for smaller systems (50 kVA and smaller) may be mounted in cabinets or on open racks. Batteries used in cabinets are normally the valve regulated (VRLA) type sometimes referred to as "maintenance free" type. Also, the individual units normally have a voltage rating of 12 volts. Battery cabinets are supplied prewired with all inter-connections factory made. The use of battery cabinets is common for lead-acid batteries in smaller systems and for nickel-cadmium (ni-cad) batteries. Lead-acid batteries for larger installations are normally mounted on open racks. In open rack installations, the individual battery cells are mounted on a rack or group of racks specially constructed for this purpose. The racks are constructed of steel rails, frames, and braces. The battery cells rest on plastic channels. The rack is factory painted with acid resistant paints. The racks may be of a variety of configurations as shown in figure 4-2. The battery rack configuration is usually determined by the cell dimensions, the number of cells, and the space available. Lead-acid cells are connected by specially designed inter-cell connectors made of lead-plated flat copper. Ni-cad cells can be connected by specially designed inter-cell connectors made of flat steel. Inter-tier, inter-rack, and inter-row connectors are also specially fabricated for the cell and rack type used.

b. Installation requirements. The static UPS system should be located indoors in a clean, dust free, low humidity location. The charger/inverter cabinets may be located in the same room with the battery. However, for larger systems, it is preferable to locate the battery in a separate room for additional safety. The charger/inverter cabinets should be located as close as practical to the battery to minimize the voltage drop in the battery leads. Personnel access should be limited to the battery and charger/inverter. The manufacturer's instructions and National Electrical Code (NEC) instructions shall be consulted for access and arrangements. The UPS cabinets should not be located directly adjacent to office space and work areas unless provided with acoustically treated enclosures. Although the noise level of static UPS systems is low, the humming caused by the electromagnetic components (transformers and reactors) may be irritating. Finally, since the static UPS system causes power supply source voltage distortion, the effect of distortion on other equipment supplied from the same bus as the UPS system should be taken into consideration. To eliminate the effect of voltage distortion on other equipment, it is advisable to supply larger UPS systems by a dedicated distribution transformer whenever possible. When the use of a dedicated transformer is not feasible and a double-ended substation is available, the loads should be distributed between the two buses as shown in figure 4-3 to minimize the effect of voltage distortion. By this arrangement, when the UPS goes to bypass, the loads are supplied from a distortion free source through the transfer switch.

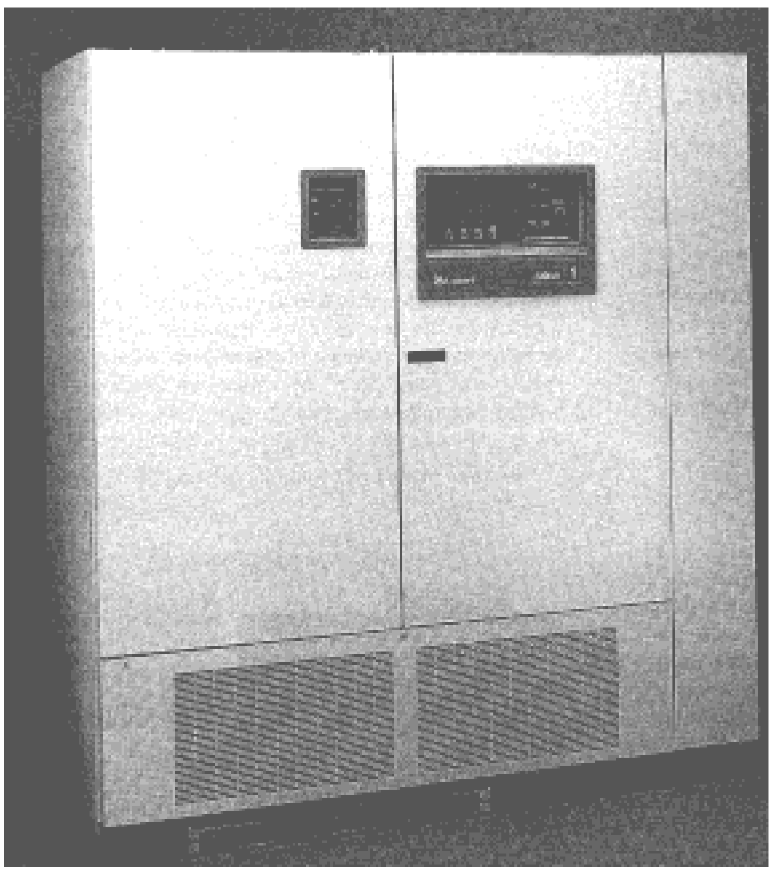


Figure 4-1. Static UPS system 150 to 750 kVA (courtesy of Liebert)

(1) Charger/inverter cabinets. The charger and inverter cabinet assemblies shall be installed on a level surface. The assemblies may be bolted to the floor if required by the manufacturer. The cabinets should be in a convenient location for periodic inspection with sufficient front clearance for front door opening and access to the cabinet internals. Sufficient

rear and overhead clearances should also be maintained for removing rear panels when necessary and for ventilation. The minimum clearances should be as recommended by the manufacturer. The charger/inverter cabinets are normally factory wired. The field wiring consists of connecting the ac input to the rectifier/charger, the alternate ac source to the bypass equipment when used, the battery leads, and the connections to the output distribution panel. The positive and negative battery leads should preferably be run in separate non-metallic conduits. The cables from the normal and the alternate ac sources should also be run in separate conduits to avoid common failures. The room temperature should be maintained below 104°F for maximum equipment life. However, when batteries are installed in the same room as the rectifier/inverter cabinets, a lower room temperature (approximately 77°F) is desirable. A ventilation system may be required

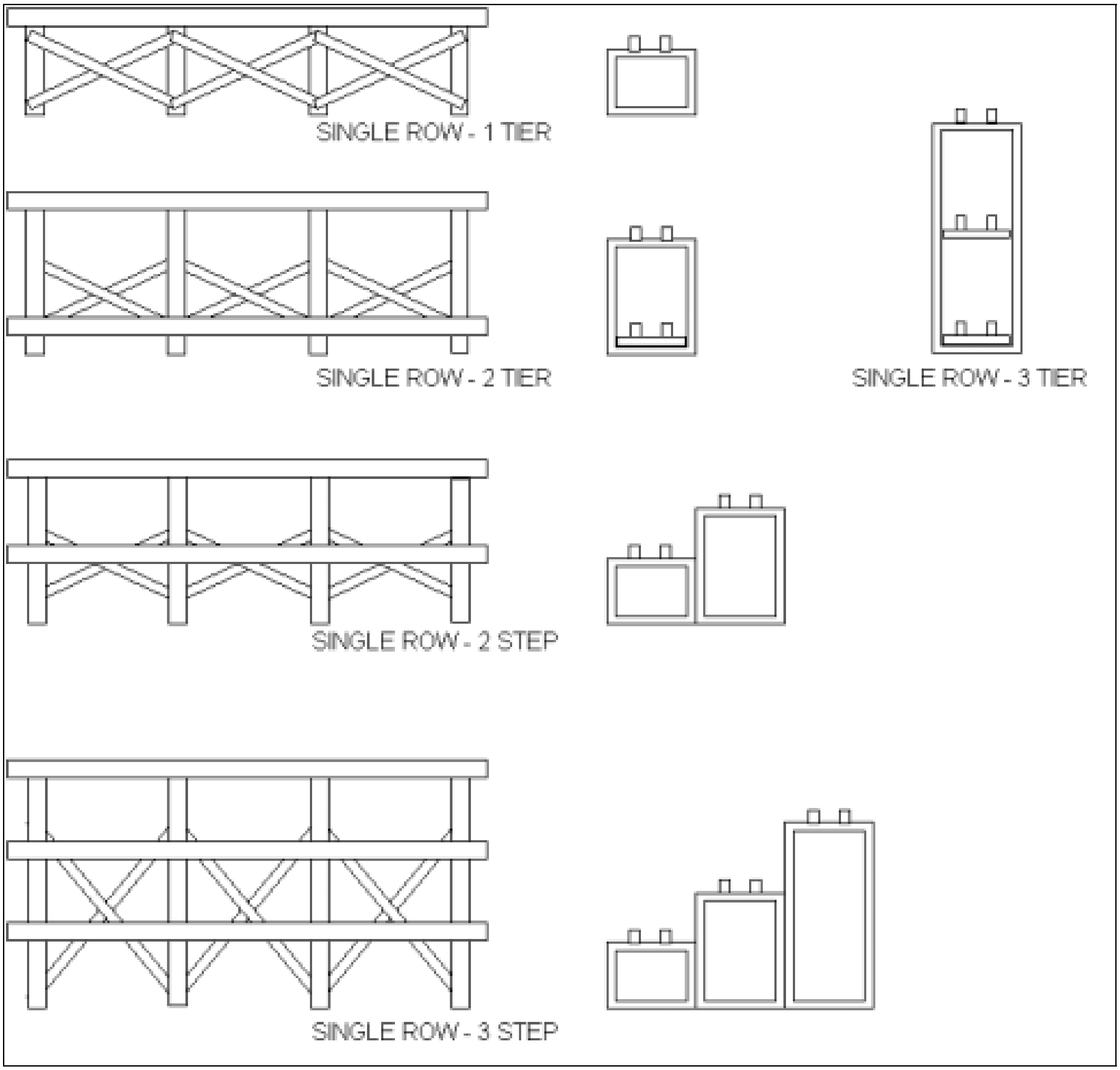


Figure 4-2. Various battery rack configurations (courtesy of Excide Technologies)

to remove the heat load generated by the UPS system and maintain the required room temperature. The approximate heat load generated by the UPS in BTU/hr is:

1500 x UPS kVA for systems rated up to 20 kVA
1000 x UPS kVA for systems rated above 20 kVA

The need for a ventilation system should be determined on a case-by-case basis. Consideration should be given to the load carrying capacity of the floor where the charger/inverter cabinets are to be installed. Also, the availability of freight elevators with adequate capacity for moving large systems in office buildings should be ensured.

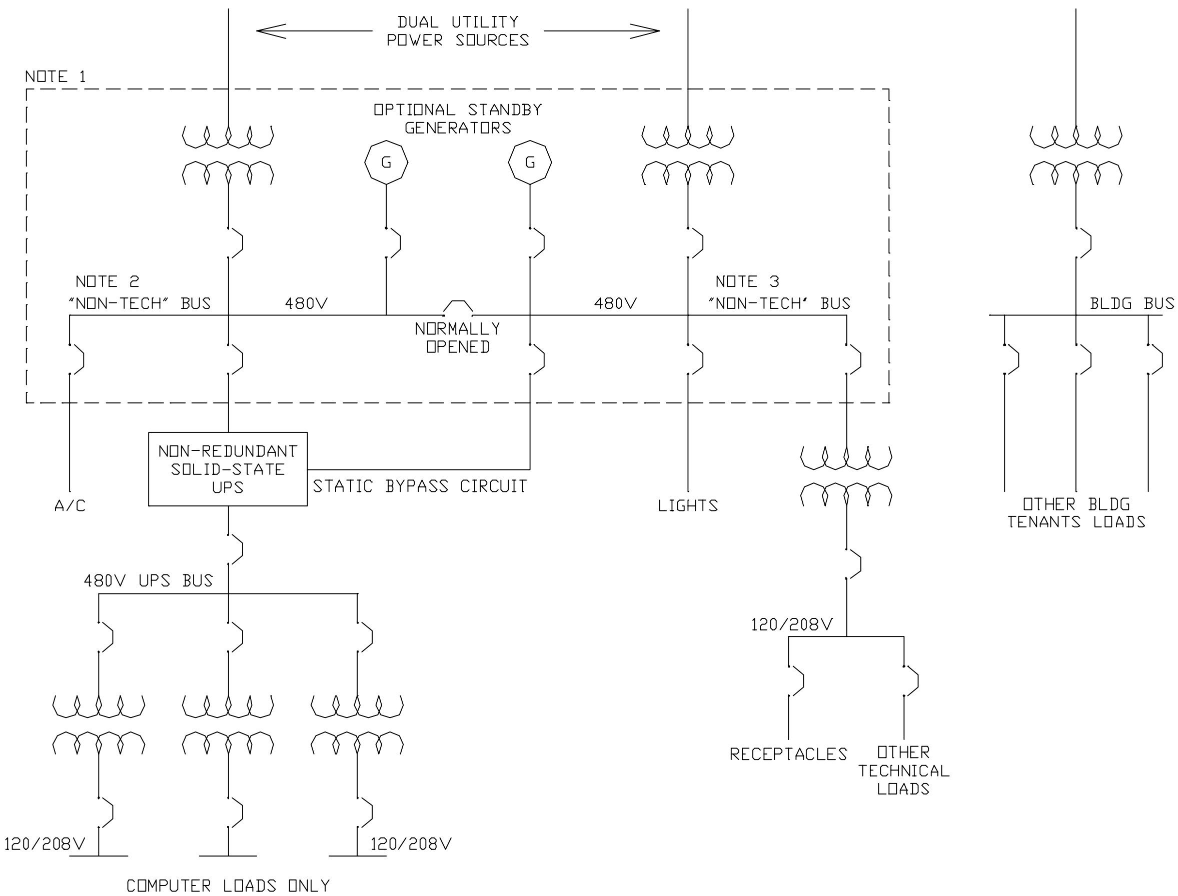
(2) Batteries and racks for larger systems. The battery racks should be located to allow access to the cells for periodic maintenance. It is recommended that the battery be installed in a clean, cool, dry location. Cells should not be exposed to heating units, strip heaters, radiators, steam pipes, or sunlight. Any of these conditions can cause a serious electrolyte temperature variation among cells within a battery. In large battery installations, whenever possible, a floor drain with acid or alkaline proof piping to a collection tank (depending on the cell type used) should be located near the rack to permit draining any electrolyte that may spill accidentally. However, it may be desirable to use a pan directly underneath the batteries. Due to the excessive weight of lead-acid batteries, it should be ascertained that the battery room floor has a weight carrying capacity that exceeds the load of the batteries and racks. The battery room should be provided with sufficient ventilation to prevent hydrogen gas accumulation in the room air. The ventilation equipment should be such that the battery room air is changed 2.5 times each hour. The objective of the room ventilation is to keep the hydrogen concentration in the room air to less than 1 percent by volume. If it is required to establish that the ventilation of the battery room is adequate, then it is necessary to calculate the rate of evolution of hydrogen gas in the room. The following method is used.

$$C = \frac{FC}{1000} \times \frac{AH}{100} \times K \times N$$

$$A = \frac{C}{0.01}$$

Where:	C	=	Cubic feet of hydrogen per hour
	FC	=	Float current, in milliamperes per 100 AH (temperature compensated)
	AH	=	Ampere hours
	K	=	Constant – 1 AH = 0.016 cubic feet of hydrogen
	N	=	Number of cells
	A	=	New air required
	0.01	=	1 percent maximum concentration of hydrogen

It is also important to maintain the average ambient room temperature at around 77°F. Higher average ambient temperatures substantially shorten the life expectancy of lead-calcium batteries. An average ambient temperature of 95°F shortens the life expectancy by about 50 percent. The NEC insulation restrictions require that battery strings rated over 250 volts be installed in groups having a total nominal voltage of not over 250 volts on any one rack. Sectionalizing protection for each 250 volt group is highly recommended. For battery strings rated under 250 volts, batteries having rubber jars must be sectionalized into groups rated at 150 volts or less. Vented alkaline-type batteries in conductive material jars cannot be installed with more than 20 cells (24 volts) in any one tray. For safety, an eyewash and quick drench facilities shall be located nearby.



NOTES

1. Utility source is double-ended substation connected in secondary selective configuration with either BUS capable of carryingthe entire load.

2. "NON-TECH" Bus feeds large cyclic motor loads or harmonic (UPS rectifier) loads.

3. "TECH" Bus feeds non-cyclic loads, light receptacles and other techincal loads.

4. Computer loads of different types or manufacturers are isolated utilizing Computer Power Distribution Centers equipped with shielded transformers, transient supressed branch circuit breakers and meterings.

DNT/Ups-tm-1

Figure 4-3. Double-ended substation connected in secondary selective configuration

4-2. Construction and installation of rotary UPS systems

The construction and installation of the UPS are critical to its proper operation.

a. Construction features of rotary systems. There are several construction features about the UPS that contribute to the system as a whole.

(1) Motor-generators (M-G) and controls for rotary systems. The M-Gs used in rotary UPS systems are normally of the horizontal type. The M-Gs can be built into a single frame or in separate frames coupled together and mounted on a common base. The M-G can be mounted without enclosures or enclosed in a sheet metal cabinet. In constructions without an enclosure, the control and monitoring devices are installed in one or more small cabinets mounted on the M-G frame(s). In constructions with an enclosure, the control and monitoring devices are normally mounted in a free-standing cabinet attached to the M-G enclosure. An inertia-driven ride-through system with a synchronous motor rotary UPS with a power range of 200 to 10,000 kVA is shown in figure 4-4. In addition to the M-G, various protective and control devices may be used on rotary systems including a thermal magnetic circuit breaker at the ac motor input

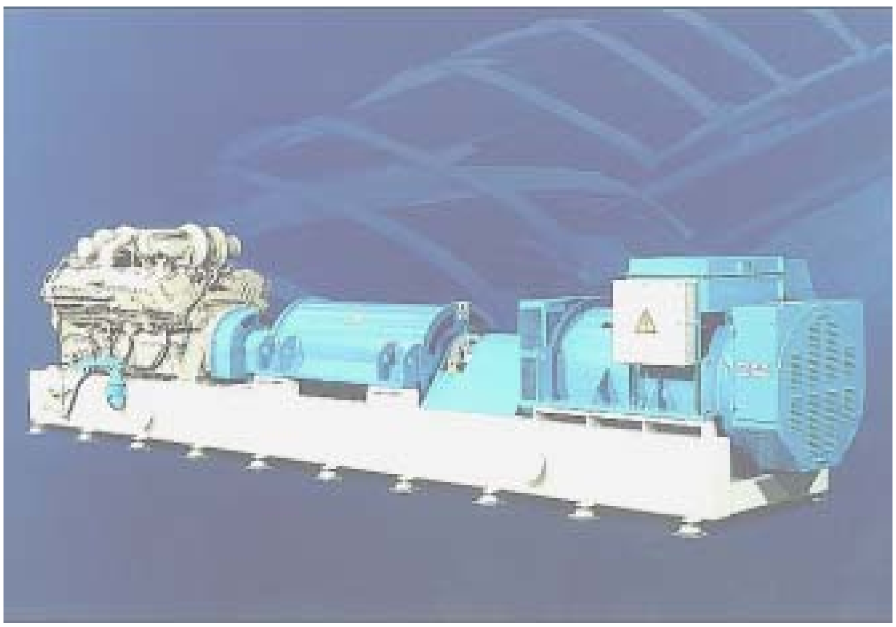


Figure 4-4. Rotary UPS system 200 to 10,000 kVA (courtesy of HITEC Power Protection)

(with indicating lights to indicate the breaker open/close position), an ac contactor used along with the input circuit breaker, a thermal magnetic circuit breaker with ac contactor and indicating lights at the generator output, and a dc contactor at the dc motor input in systems with a dc motor and a backup battery. Relays to detect and alarm loss of ac input/output and loss of dc input in systems with a backup battery may also be provided. The control cabinets are normally designed for front access. All components can be operated, inspected, or removed from the front of the cabinet by opening a hinged door. Meters, indicating lights, control switches or pushbuttons, and adjustment potentiometers may be located inside the cabinet or mounted on the hinged door. The cabinet doors are provided with screened filtered openings for cooling. Cooling is normally by natural convection. Enclosure-mounted cabinets are normally designed to allow power and control cables to enter from the top. Free-standing cabinets are designed to allow the power and control cables to enter from either the top or the bottom. In some designs the motor and generator are vertically mounted on a common vertical shaft to reduce the required floor space. Reducing the floor space may also be accomplished by stacking the motor and generator and coupling their horizontal shafts using pulleys and belts. Some designs are also available with a common motor and generator in one rotor to optimize the machine size.

(2) Batteries and racks for rotary systems. Construction of rotary UPS system batteries and racks is the same as the static UPS system batteries discussed in paragraph 4-1a(2).

b. Installation requirements for rotary systems. The rotary UPS system can tolerate a larger range of environmental conditions than the static UPS. The room may range from temperatures of 5° to 40° C while operating, -20° to 80° C while not operating. The humidity may range from 0 to 95 percent non-condensing for all temperatures mentioned. The UPS is suitable for installation in industrial electrical environments. Where applicable, the charger/inverter cabinets should be located as close as practical to the battery to minimize the voltage drop in the battery leads. Also, the UPS shall be close to the protected load if possible. The UPS cabinets should not be located directly adjacent to office space and work areas unless provided with acoustically treated enclosures.

(1) M-G and controls installation. The M-G and cabinet assemblies shall be installed on a level surface. The assemblies may be bolted to the floor if required by the manufacturer. The cabinets should be in a convenient location for periodic inspection with sufficient front clearance for front door opening and access to the cabinet internals. Sufficient rear and overhead clearances should also be maintained for removing rear panels when necessary and for ventilation. The minimum clearances should be as recommended by the manufacturer. The rotary UPS can tolerate a range of temperatures of 5° to 40° C while operating, and -20° to 80° C while not operating. However, when batteries are installed in the same room, a lower room temperature (approximately 77°F) is desirable. The need for a ventilation system should be determined on a case-by-case basis. Consideration should be given to the load carrying capacity of the floor where the rotary UPS is to be installed. Also, the availability of freight elevators with adequate capacity for moving large systems in office buildings should be ensured.

(2) Battery and rack installation for rotary systems. Installation of rotary UPS system batteries and racks is the same as the static UPS system batteries discussed in paragraph 4-1b(2).

4-3. Power distribution and equipment grounding and shielding requirements

An UPS system, whether static or rotary, single-phase or three-phase, has a single output. The UPS system, however, usually supplies a variety of loads, each of which should be independently protected so that a fault on one circuit will not cause loss of all others.

a. Power distribution equipment. There are three critical functions of a well designed UPS ac distribution system. First, short circuit protection of all underground conductors; second, isolation of panel pull-down during a branch fault; and third, isolation of the critical loads from electrical noise coupled through the static bypass. The power distribution system will usually consist of a panelboard, with circuit-breakers or fuses to protect the individual branch circuit conductors which will usually be run in conduits dedicated to these uninterruptible circuits.

(1) Panelboards. A panelboard consists of a sheet steel housing containing a set of bus bars, enclosed in a molded insulated housing, which also provides mounting for the branch circuit protective devices. A single-phase UPS will require two bus bars while a three-phase UPS will require three. A neutral bar, insulated from the enclosure but otherwise bare, will be provided in

both single-phase and three-phase boards. A front panel, usually screwed to the enclosure, contains a door for access to the protective devices while completely enclosing the wiring and terminals.

(2) Circuit breakers. Molded-case circuit breakers are either plugged into or bolted onto auxiliary bus bars attached at right angles to the main bus bars. Circuit breakers may be single-pole or two-pole in single-phase boards; three-phase boards may in addition contain three-pole breakers. Manual switching as well as automatic overcurrent tripping of the various branch circuits is provided by the circuit breaker, which disconnects all ungrounded circuit conductors simultaneously.

(3) Fused switches. As an alternative to circuit breakers, fused switches may be used. The switch provides for manual control and the fuse provides automatic overcurrent protection. Switches may have one, two, or three poles as with circuit breakers.

(4) Neutral bus. An UPS system will usually supply at least some line-to-neutral loads, and a neutral bus will be provided. This bus contains provision for both a main neutral conductor and a grounding conductor, as well as terminations for the branch circuit neutral conductors. The neutral bus must not be grounded to the enclosure, either accidentally or intentionally, in spite of the provision of a grounding terminal. The neutral ground is applied at the UPS and at the bypass source and must not be duplicated at the panelboard. Also, in a three-phase UPS system with a transfer switch, the neutral conductor should not be opened with the transfer switch.

(5) Coordination of protection. When a fault (or short circuit) occurs on a branch circuit, the branch circuit breaker or fuse must isolate the fault before the UPS protective devices operate and trip the entire system. When this condition is fulfilled, the protection system is said to be coordinated. Fuses of different ratings can be coordinated, so a main panelboard may supply a downstream panel if necessary, however, it rarely is necessary and should be avoided. Molded-case circuit breakers are instantaneous in action at currents above 8 to 10 times their continuous current rating. Since the UPS has limited output current, additional power for clearing fault currents rapidly may be provided from an alternate high power source by the use of a static switch. When a fault occurs on any branch circuit, the inverter reaches the current limit condition and the bus voltage falls almost to zero, thus depriving all branch circuit loads of power. The permissible duration of this loss of power must be longer than the clearing time of the breaker plus the transfer switching time in the UPS if the coordination is to be obtained.

(a) Branch circuit breakers. Branch circuit breakers are selected based upon the voltage rating, the normal full load current of each branch circuit load (continuous and intermittent loads), the inrush current and its duration for each branch circuit load, the maximum time each connected load can tolerate a loss of voltage without failure (time for failure), and the available short circuit current at the uninterruptible ac main bus through the inverter or the by-pass circuit when a static transfer switch is used (to be obtained from the UPS system vendor or calculated).

(b) Fuses. Like circuit breakers fuses must have adequate voltage rating. Select the fuse ampere rating for each branch circuit to be as close as possible to the full load current of the connected load. Check from the fuse melting curve that the fuse melting time at a current equal to the connected load inrush current is longer than the duration of the load inrush current. If this condition is not satisfied, increase the fuse size as required. The branch circuit fuse with the largest rating shall have a clearing time which when added to the static transfer switch total

transfer time (normally 4 milliseconds (msec) or less) shall be less than the time the most critical load can tolerate a loss of power.

b. Grounding. The usual electrical power system utilizes two grounding methods; their purposes are quite different. System grounding is the intentional grounding of the neutral point of devices to provide equipment protection by suppressing transient and sustained overvoltages caused by fault conditions. Equipment grounding is provided as protection against accidental grounds by interconnecting a low-impedance path from all noncurrent-carrying metallic parts, thus minimizing potential gradients while ensuring sufficient fault current to trip protective devices.

(1) System grounding. The neutral of a single-phase, three-wire system and of a three-phase four-wire system should always be grounded. As explained in paragraph 4-3a(4), the neutrals of the UPS and of the bypass source should be grounded and not the neutral bar in the distribution panel board.

(2) Equipment grounding. For safety reasons, all electrical equipment enclosures, including metallic conduits, must be effectively grounded per the NEC. Although all raceways and enclosures are bonded together to form a continuous ground path, grounding of enclosures to the nearest ground point is recommended. The ground point may be a structural member which is part of a bonded and grounded network of steel beams and columns, a ground conductor, or to a ground rod driven into earth. The connection between the equipment enclosure and the ground point should be as short as possible to achieve the maximum in noise reduction, particularly at the higher frequencies.

(3) Single point grounding. In addition to grounding the system neutral to facilitate ground fault isolation and grounding the equipment enclosures to avoid the hazard of electrical shocks, the grounding system should minimize the generation of unwanted noise. The generation of unwanted noise can be minimized by equalizing the voltage to ground of all the system components. This is done by establishing single-point grounding. The single-point grounding is established by connecting the grounding conductors of all the system component enclosures to the power source neutral grounding point as shown in figure 4-5. For the single-point grounding system to be effective, the equipment grounding conductors should be as short as possible. This requires that the UPS system be located adjacent to or in the same room with the supplied equipment. In installations where this cannot be accomplished and the UPS system is located away from the loads, an isolation transformer should be used. The isolation transformer is interposed between the UPS output and the loads and should be located in the same room with the supplied loads. The isolation transformer grounded secondary neutral is used as the grounding point to connect all the equipment grounding conductors.

(4) Ground loops and multipoint grounding. The single-point grounding system should be used whenever feasible. However, within very large systems the use of a single-point grounding may not be practical. The system may be made of subsystems each supplied from different power sources with separate central grounding points. This situation is often in installations where data terminals and remotely located printers are located outside the computer room. In such installations the different central ground points may have different potential to ground and ground loops are established as shown in figure 4-6. Such ground loops can create a path for

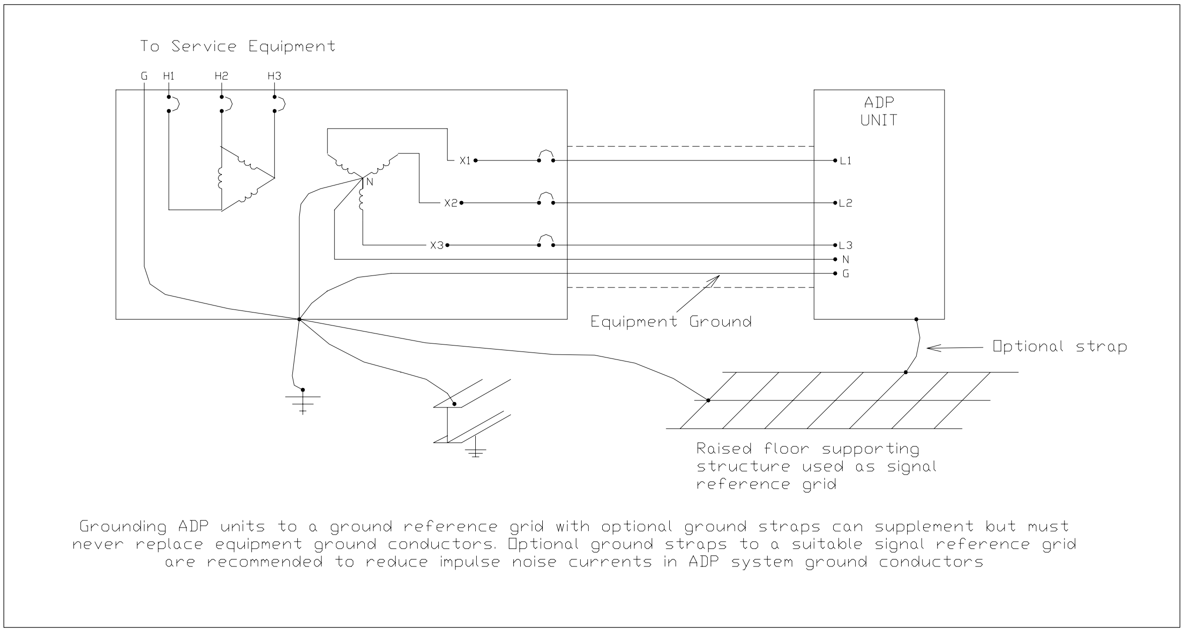


Figure 4-5. Single-point grounding example
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unwanted noise through the data links between the different components. Ground conductors of low resistance interconnecting the separate central grounding points shunts some of the noise current away from the data cable as shown in figure 4-6.

c. Computer power centers. A computer power center is a self-contained unit which can be located in a computer room to distribute the power from the UPS system to the loads. It contains an isolation stepdown transformer, output circuit breakers, and terminations for main input power cable and output cables. A computer power center may also contain a power monitoring panel which monitors the input/output power and system faults and records power disturbances. The contained isolation transformer in a computer power center isolates noise that may be produced in the power cable from the UPS output and allows establishing an effective single-point grounding system. Additionally, the output cables have specially fabricated grounding wires which tie the equipment enclosures to the single-point ground through plug-in connectors. There should be no other grounds on the neutral conductors which must be insulated for their entire length, including the wiring in the equipment supplied by the branch circuits.

d. Shielding. Low-level signal cables to instruments should never be run in the same raceway as power cables. While signal (or instrumentation) cables are usually shielded and/or twisted to reduce noise pickup, it is practically impossible to provide shielding of power cables to eliminate transmission of low frequency energy. Using grounded metal enclosures, such as conduit or solid tray, for all the distribution circuits will eliminate most of the higher frequency energy radiated by the power cables.

e. Radio frequency interference (RFI). Shielding as described in paragraph 4-3d. above effectively eliminates the RFI that may be caused by harmonics in the UPS output. The RFI effects that may be caused by radiated noise from the UPS components can be minimized by maintaining adequate space between the UPS and susceptible equipment. A spacing at

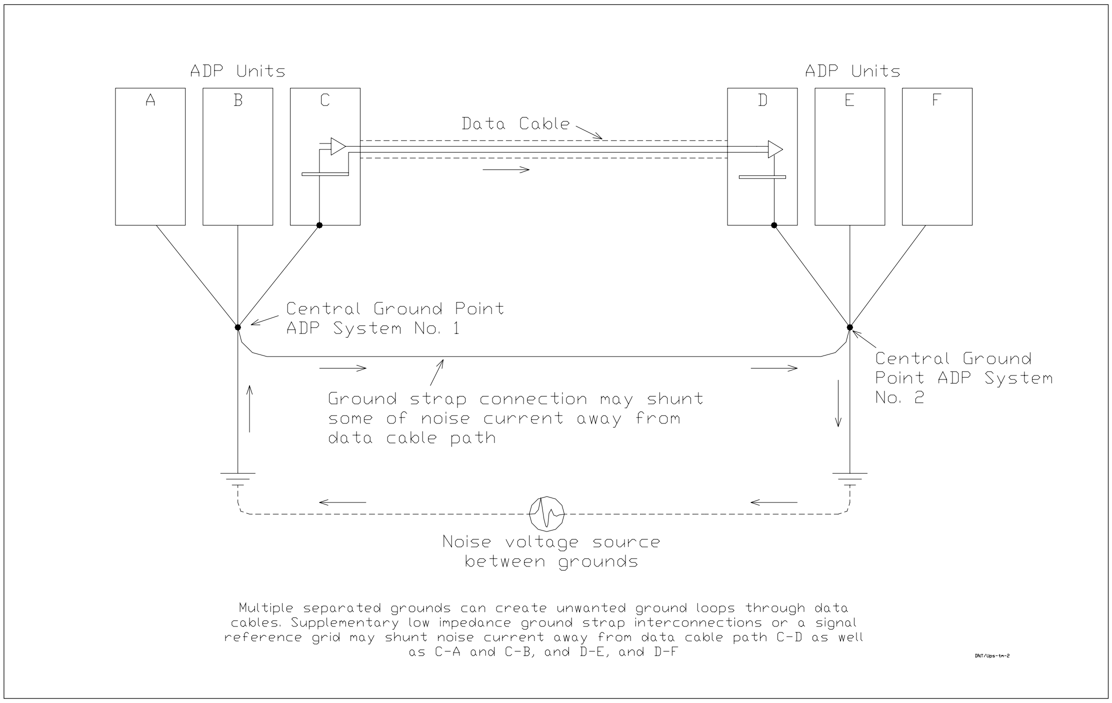

Figure 4-6.. Multipoint grounding example
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25 feet is considered adequate in most applications. Also, a suppression plate attached to the junction box located in the computer room for connecting the incoming power cable to the local distribution panel can be used to attenuate the radio frequency (RF) noise which may propagate along the incoming power cable.

*f. Noise and noise reduction met*hods. Noise is unwanted current and/or potential induced in the signal cables by adjacent sources. Noise can be induced in the signal cable in the following two modes. Differential mode, where the induced noise causes the potential of one side of the signal path to change relative to the other side. Common mode, where the induced noise appears between both signal leads and the common signal reference ground and causes the potential of both sides of the signal path to change simultaneously and by the same amount relative to the common reference ground. Noise is generally induced by electromagnetic coupling, electrostatic coupling, and ground potential differences. Noise reduction methods are highly specialized and are specific to the application. They also depend on the installation configuration, the proximity and nature of sources of interference, frequency of the interference signals, etc. However, noise can generally be reduced by providing proper grounding, avoiding ground loops, providing electrostatic and electromagnetic shielding of signal circuits, and providing separation of circuits.

4-4. Testing and start-up

The purpose of electrical testing on systems and their components is two-fold. The first is to check the installation of the equipment and perform component and systems tests to ensure that, when energized, the system will function properly. The second is to develop a set of baseline test results for comparison in future testing to identify equipment deterioration. The system should be initially checked for damage, deterioration, and component failures using specific component checks, inspections, and tests defined by the equipment manufacturer. Then the interconnection of the system components should be checked, using de-energized and energized methods, to verify the proper interconnection and operation of the components, including on/off control, system process interlocks, and protective relaying functions. Once the above tests are complete, the system can be energized and operational tests and measurements should be performed. All steps and results of the testing should be carefully documented for review and for use in the future for comparison with the results of future tests. Many of the same component tests initially run will be performed at regular intervals as part of a maintenance program. The new results will be compared to the initial results, where variations may be indicative of problems like deterioration of insulation or dirty equipment. A test program will commence after completion of installation and will usually include field inspection and installation checks, de-energized component testing, verify instrument and relay operation and calibration, visual check of all wiring, continuity checking of control circuits, energized functional testing of control circuits, megger testing of power circuits, test of power circuit phasing, energizing of equipment, and service testing. If problems are found during the testing, an analysis should be performed, and a repair and retest should be performed that is approved by the manufacturer, engineer, and system operator. Many of these initial tests will be repeated periodically as part of the system maintenance program depending on the load conditions, duty cycle, environmental conditions, and the critical nature of the equipment. Because of this, the completeness and clarity of the test reports is important as they supply baseline data for comparison with the results of the maintenance tests. Many tests on electrical equipment involve the use of high voltages and currents that are dangerous, both from the standpoint of being life hazards to personnel and because they are capable of damaging or destroying the equipment under test. Adequate safety rules should be instituted and practiced to prevent injury to personnel, both personnel who are performing the tests and others who might be exposed to the hazard. Also, the test procedures used should be designed to ensure that no intentional damage to equipment will result from the testing process. There are four categories of tests for electrical equipment: factory, acceptance, routine maintenance, and special maintenance. Factory tests are performed at the factory to prove the equipment was manufactured properly and meets specific design parameters. Acceptance tests are also proof tests performed on new equipment and systems usually after installation and before energization. They are run to determine whether the equipment is in compliance with specifications, to establish benchmarks for future tests, to determine the equipment was installed without damage, and to verify whether the equipment meets its intended design operation and limits. Routine and special maintenance tests are run after the equipment has been in service for a certain amount of time to determine the degree of deterioration of certain equipment physical parameters as operating time increases. Routine tests are performed on a periodic basis and special tests are performed on defective equipment to help determine the cause of a failure and/or the extent of the damage. The same type of tests and measurements are performed for all of the categories using different voltage values. The acceptance tests are usually run at 80 percent and the maintenance tests are usually run at 60 percent of the factory test voltage values to help indicate deterioration without being destructive. The following paragraph discusses the acceptance testing. The routine and special maintenance testing is discussed in chapter 5. Acceptance testing is a system verification and functional performance test which should be performed on the UPS system. These tests will include installation inspections, individual component testing, testing on wiring, control and interlock functional checks, equipment energization and system operating measurements, and functional checks.

a. Installation inspection. Field inspection and installation checks include the inspection of the component nameplates, inspection of components for damage and cleanliness, inspection of insulators for cracking, inspection of anchorage and grounding, sizing check of fuses and breakers, alignment and adjustment checks, mechanical operation and interlock checks, lubrication application, verification of insulating liquid or gas level or pressure, and verification that local safety equipment is in place.

(1) UPS. The UPS system shall be inspected for completeness of assembly, verification of nameplate, sizes and settings against drawings, loose parts and insulation damage, and proper settings.

(2) Battery. The battery should be inspected for completeness of assembly, verification of nameplate, sizes and connection against drawings, loose parts, leaks or damage, electrolyte level (flooded batteries), and vents sealed and plugs installed (if applicable).

(3) UPS switchboard. The UPS switchboard should be inspected for completeness of assembly, verification of nameplate, sizes and settings against drawings, and loose parts and insulation damage.

(4) Motor inspection. The motors should be inspected for completeness of assembly, verification of nameplate, sizes and connection against drawings, loose parts, foreign materials or damage, check insulation type, and alignment of motor with generator.

(5) Generator inspection. The generators should be inspected for completeness of assembly, verification of nameplate, sizes and connection against drawings, loose parts, foreign materials or damage, proper mounting and grounding, and alignment of motor with generator.

b. Individual component testing. De-energized component testing typically includes megger and insulation resistance testing of equipment and connections including grounds, turns ratio measurements, polarity tests, power factor or dissipation factor tests, overpotential tests, contact resistance measurements, operation time travel analysis, battery and cell voltage measurements, charger/UPS/generator current and voltage measurements, and equipment/systems impedance or resistance tests. The following components of the UPS system will be tested as follows.

(1) UPS systems. The static UPS system consists of the battery charger, inverter, battery, and static switch. In addition to these items the rotary UPS consists of a motor and a generator. These items are individually listed.

(2) Battery chargers. A battery charger is an electronic device that converts ac power to dc power. The charger supplies this dc power to the battery. As with all electronic devices, this device should not be megger tested. A visual inspection should be performed to verify the correctness of installations, supports, grounding, and wiring. The rating nameplate should be checked to ensure that both the ac supply to the charger and the battery to be connected corresponds to the charger's parameters. Check to ensure all shipping and other debris in and around the charger cabinet are removed. Check settings of the charger and calibrate per manufacturer's manual to match the battery (float and equalizing levels). If the battery charger has been factory set, check the charger float and equalizing voltage levels against drawings and specifications. If not, set the charger float and equalizing voltage levels to those listed on drawings and specifications. Before connecting to the battery, measure the output voltage provided by the charger and record. Verify that all charger functions and alarms operate correctly. Verification that the battery is connected to the battery charger properly is extremely important. The negative wire from the negative terminal of the battery must be connected to the negative terminal of the charger. Similarly, the positive wire from the positive terminal of the battery must be connected to the positive terminal of the charger. As with the interconnections

for all other equipment, the cables used should be megger tested as described in the paragraph 4-4.a.

(3) Inverter. The inverter is similar in construction to the charger. It converts dc power to ac power using solid-state electronics and should generally be tested using the same methods. Therefore, this device also should not be megger tested.

(4) Static switch. The inverter is similar in construction to the charger and inverter. It is constructed of solid-state electronics and should generally be tested using the same methods. Therefore, this device also should not be megger tested.

(5) Battery testing. The individual cell condition check includes visual inspection of cell integrity investigating evidence of corrosion at terminals, connections, racks, or cabinet. The general appearance and cleanliness of the battery, the battery rack or cabinet, and battery area including accessibility should be observed. The cells should be checked for cracks in cell or leakage of electrolyte as well as the integrity of the cover. Electrolyte should be added to any cell in which the electrolyte level is below the top of the plates. If the battery cells are not delivered filled, it is recommended that they be filled according to manufacturer's recommendations before installation on racks. Before installation, the voltage of each cell should be measured. The voltage measured should be equal to or less than 0.05 volts below the manufacturer's open circuit voltage. If it is not, the manufacturer should be contacted to determine the next course of action. The cell polarity for positive to negative connections should be checked. The battery should be assembled as shown on drawings. Each battery cell is then checked to ensure the electrolyte level is at the maximum level. The interconnection of the battery cells should be checked for polarity. The connector bolts should be checked to ensure that they have been tightened to the manufacturer's recommended torque values. The cell internal ohmic values and the inter-cell connection resistances are then measured. This is accomplished by applying a load across the battery and measuring the step change in voltage and current for each cell taken between the positive and negative terminal posts of adjacent cells as well as the battery as a whole. The ohmic value is the change in voltage divided by the change in current. The resistance values for each cell should be averaged and any interconnection that varies more than 10 percent or 5 $\mu\Omega$ over the average should be remade and then rechecked for its resistance value. These values shall become baseline values for comparison in future tests. The presence of flame arrestors, adequacy of battery support racks, mounting, anchorage, grounding, and clearances, ventilation of battery room enclosure, and existence of suitable eyewash equipment should be verified. After completion of the above inspections the battery is ready for charging. After charging, measure each cell voltage and total battery voltage (with charger in float mode of operation), ac ripple current, specific gravity, electrolyte temperature (visually check fill level), overall float voltage at the battery terminals, charger output current and voltage, and ambient temperature. Also check the condition of ventilation and monitoring equipment and the temperature of the negative terminal of each cell of the battery. When the battery is charged, use a voltmeter to check the polarity of the series connections. The total voltage should be measured both across the battery and between adjacent cells and should be compared to the specified voltage. The total voltage should approximately be the resultant of the quantity of cells multiplied by the typical cell voltage. A variation is an indication that the battery may be improperly assembled.

(a) Discharge test. For the acceptance test the discharge rate should be at a constant current or constant power load equal to the manufacturer's rating of the battery. The charging method used as a basis for published data is an important factor. For a stationary float application, data based on prolonged constant potential charging should be used. If constant current charging has been used to establish the published data, appropriate float charging

correction factors should be obtained from the manufacturer. Note that the test discharge current is equal to the rated discharge current divided by the temperature correction factor for the initial electrolyte temperature. Set up a load and the necessary instrumentation to maintain the test discharge rate determined above. Disconnect the charging source, connect the load to the battery, start the timing, and continue to maintain the selected discharge rate. If the charging source cannot be disconnected, the current being drawn by the load has to be increased to compensate for the current being supplied by the charging source to the battery. Read and record the individual cell voltages and the battery terminal voltage. The readings should be taken while the load is applied at the beginning and at the completion of the test and at specified intervals. There should be a minimum of three sets of readings. Individual cell voltage readings should be taken between respective posts of like polarity of adjacent cells so as to include the voltage drop of the inter-cell connectors. Maintain the discharge rate and record the elapsed time at the point when the battery terminal voltage decreases to a value equal to the minimum average voltage per cell as specified by the design of the installation times the number of cells.

(b) Capacity check. The capacity of the battery is checked using the following equation.

Percent capacity at the test rate at 25 ºC (77 ºF) = (t_a / t_s) x 100

Where: t_a is the actual time of the test to specified terminal voltage as corrected for temperatures

t_s is the rated time to specified terminal voltage

(6) Motor testing. Testing of motors will vary based on the size of the motor. Small size motors, less than 200 HP require mechanical testing and insulation resistance testing (megger). Medium size motors, between 200 and 5000 HP require mechanical testing, insulation resistance testing (megger), and polarization index testing. Large size motors, greater than 5000 HP require mechanical testing, insulation resistance testing (megger), polarization index testing, and overpotential testing (Hi Pot).

(a) Motor mechanical test. A mechanical test of the motor should be performed to check that the motor is free from interference. This is accomplished by first uncoupling the motor from the driven machinery. The motor shaft is then manually rotated. The shaft should rotate freely.

(b) Motor insulation resistance test (megger). This test is performed to ensure the insulation has no weaknesses. The test is performed utilizing a megohmmeter, either hand or power operated, with a voltage output of at least 1000 volts. The test should be conducted phase-to-phase and phase-to-ground. Test duration should be one minute. The insulation resistance is variable with temperature, thus the measured value should be corrected to the standard temperature as required. The recommended minimum values of insulation resistance are rated kilovolts (kV) plus 1 megohm for the stator winding (for example, 5.16 megohms for 4.16 kV winding) and 1 megohm for the rotor winding. While this is a guideline, the manufacturer's test manual shall include acceptance criteria for the test. Megger test are “go/no-go” tests.

(c) Motor polarization index test. The polarization index test is an insulation resistance test that lasts for 10 minutes. The insulation resistance is recorded after 1 minute, then again after 10 minutes. The polarization index is the quotient of the 10-minute and 1 minute

readings. After insulation resistance readings have been made, the test voltage is returned to zero and the insulation is discharged.

(d) *Motor overpotential testing (Hi Pot).* This test assesses the dielectric strength of the insulation of a generator. The dc over potential test is performed by applying a voltage and measuring the leakage current. The voltage applied during the acceptance test is a function of the equipment voltage rating as shown by the following equation.

dc acceptance test voltage = (2 x E + 1) x 1.7 x 0.75 kV, where E is the rated voltage in kV

The standard duration of the test is between 1 to 5 minutes. The dc acceptance test voltage is applied to each winding separately with the other windings grounded. The voltage is applied in steps. First, one third of the dc acceptance test voltage is applied. Leakage current readings are taken at 1 minute intervals for a maximum of 10 minutes. Then the voltage is increased in 1 kV intervals recording the leakage current at each step. Sufficient time shall be allowed between steps for the leakage current to stabilize. The data shall be plotted. Any sudden changes in the curve characteristics are an indication of impending winding failure.

(7) Generator testing. Testing of generators will vary based on the size of the generator. Small size generators, less than 200 HP, require mechanical testing, insulation resistance testing (megger), no load testing, and load testing. Medium size generators, between 200 and 5000 HP, require mechanical testing, insulation resistance testing (megger), polarization index testing, no load testing, and load testing. Large size generators, greater than 5000 HP, require mechanical testing, insulation resistance testing (megger), polarization index testing, overpotential testing (Hi Pot), no load testing, and load testing.

(a) Generator mechanical test. The clearance in the generator and exciter air gap should be checked. Uncouple the motor from the generator. Make sure the generator set turns over freely. Rotate the generator rotor by hand at least two revolutions to be sure there is no interference and it turns freely. Do not apply any mechanical force to generator fan when rotating generator rotor.

(b) Generator polarization index test. The polarization index test is an insulation resistance test that lasts for 10 minutes. The insulation resistance is recorded after 1 minute, then again after 10 minutes. The polarization index is the quotient of the 10-minute and 1 minute readings. After insulation resistance readings have been made, the test voltage is returned to zero and the insulation is discharged.

(c) Generator insulation resistance test (megger). This test is performed to ensure the insulation has no weaknesses. The test is performed utilizing a megohmmeter, either hand or power operated, with a voltage output of at least 1000 volts. The test should be conducted phase-to-phase and phase-to-ground. Test duration should be 1 minute. The insulation resistance is variable with temperature, thus the measured value shall be corrected to the standard temperature as required. The recommended minimum values of insulation resistance are rated kV plus 1 megohm for the stator winding (for example, 5.16 megohms for 4.16 kV winding) and 1 megohm for the rotor winding. While this is a guideline, the manufacturer's test manual shall include acceptance criteria for the test. Megger test are “go/no-go” tests.

(d) Generator over-potential test (Hi Pot). This test assesses the dielectric strength of the insulation of a generator. The dc over potential test is performed by applying a voltage and

measuring the leakage current. The voltage applied during the acceptance test is a function of the equipment voltage rating as shown by the following equation.

dc acceptance test voltage = (2 x E + 1) x 1.7 x 0.75 kV, where E is the rated voltage in kV

The standard duration of the test is between 1 to 5 minutes. The dc acceptance test voltage is applied to each winding separately with the other windings grounded. The voltage is applied in steps. First, one third of the dc acceptance test voltage is applied. Leakage current readings are taken at 1 minute intervals for a maximum of 10 minutes. Then the voltage is increased in 1 kV intervals recording the leakage current at each step. Sufficient time shall be allowed between steps for the leakage current to stabilize. The data shall be plotted. Any sudden changes in the curve characteristics are an indication of impending winding failure.

(e) No load test. This test will determine whether a problem exists in the generator or regulator system. The theory behind this test is as follows. The output voltage of a generator is dependent on its speed, design, load, and exciter input current. If the speed and exciter input are known, the output voltage at no load can be measured and compared to the design value. To conduct the test, verify that the generator is shut down and connect a voltmeter to the generator output. With no load on the generator (main breakers open) run the generator at rated speed and measure the generator output voltage. Shut the generator down and compare the voltage reading with the design value; if they match, the regulator is functioning properly.

(f) Load test. Following the no load test, perform a load test turning the generator off and attaching an ammeter to the output. Turn on the generator and add load until generator rated power is reached. Run the generator at full load for four hours, and check the temperature to ensure the unit is not overheating.

c. Visual and electrical wiring inspections. The termination of each cable, shown on the cable block and wiring diagrams, should be checked to insure each conductor matches the wiring and schematic diagrams. This is performed by yellow lining each connection from the schematic to the wiring diagram, visually inspecting each connection for cable number, wire number/color, and terminal, and checking point-to-point continuity or “ringing out” each wire from end to end including grounds.

d. Energizing and test of the UPS system. After installation and component testing, individual components of the UPS system should be sequentially energized from the source through the loads. As each item is energized, control functions, interlocks, and alarms should be checked for proper operation. Voltage, phasing, and current measurements should be made at each step. See figure 4-7.

(1) UPS (inverter/static switch). Verify the UPS is operational through the rectifier/battery charger and battery, and verify the battery is charged and on float. Measure the float voltage. Verify the UPS bus incoming breaker is open, inverters A and B breakers are open, and the static switch is switched to inverter A. Close inverters A and B input breakers, measure inverters A and B output voltage and read meters, and verify inverters A and B outputs are in phase. Verify static switch is in inverter A position, open inverter A incoming breaker and verify static switch switches to inverter B. Measure voltage and ensure a bumpless transfer is made. Close inverter A incoming breaker and verify static switch switches to inverter A. Measure voltage and ensure a bumpless transfer is made. Open rectifier/battery charger output breakers and battery breaker and verify that inverts A and B trip on low voltage.

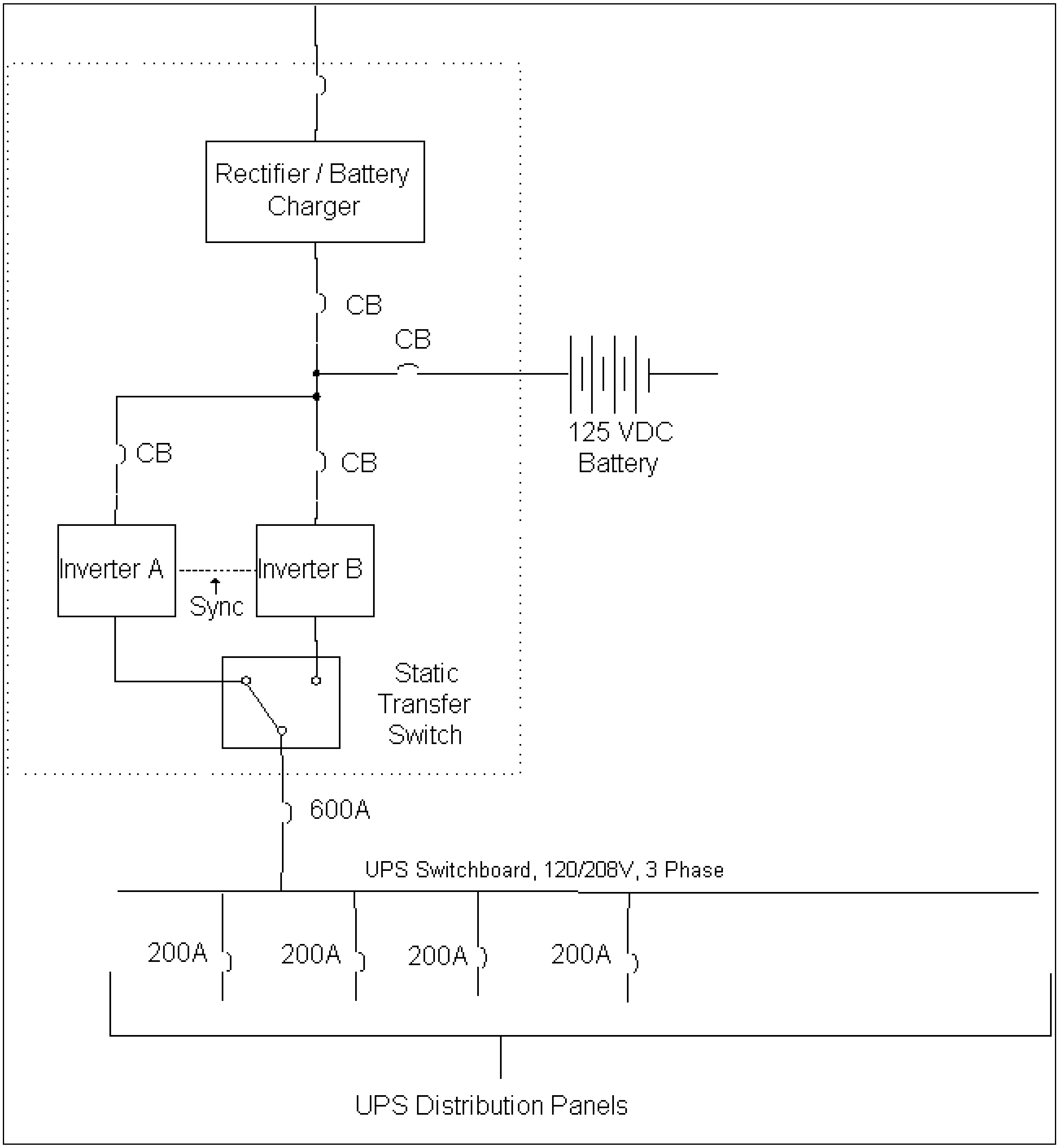

Figure 4-7. UPS distribution panels

(2) Loading UPS. Verify UPS is energized through static switch and all UPS loads are connected properly and ready to start. Close the incoming breaker to the UPS bus. Close the load breakers on the UPS bus sequentially. Measure voltage and read UPS meters at each step, and add load until the UPS reaches normal design load.

(3) *Utility trip test.* Verify the UPS is loaded and connected to the utility. Manually open the feeder breaker and verify the battery picks up load. Measure the current. Verify the transfer

switch transfers to diesel generator, the diesel generator starts and picks up load, and the battery returns to float mode. Measure voltage and current at UPS and ensure a bumpless transfer is made. Close the utility breaker. Verify the transfer switch transfers to the utility, the battery picks up load during transfer, the diesel generator stops, and the battery returns to float after the utility picks up load. Measure voltage and current at UPS bus and ensure a bumpless transfer is made.

(4) Inverter A to inverter B loaded transfer test. Verify the UPS is loaded and connected to the utility. Open inverter A incoming breaker and verify the static switch switches to inverter B. Measure voltage and current at UPS bus and ensure a bumpless transfer is made. Close inverter A incoming breaker and verify that the static switch switches to inverter A. Measure voltage and current at the UPS bus and ensure a bumpless transfer is made.

(5) Battery discharge test. Verify the UPS is loaded and connected to the utility, and notify the plant of pending UPS trip. Open the diesel generator breaker and block auto and manual start. Open the utility breaker. Verify the battery picks up load and measure battery voltage and current. Measure the UPS voltage and current and ensure a bumpless transfer is made. Operate the UPS from the battery until the battery minimum voltage is recorded (1 to 4 hours). Verify inverters A and B trip when the batteries reach minimum voltage. Notify the plant of pending UPS re-energization, reclose the utility breaker, close the diesel generator breaker, and return to auto start mode. Verify the battery is on float and charging, and measure the current. Verify when the battery is fully charged and record time to charge.

e. Test forms. Component and system test forms for the UPS, battery, UPS switchboard, motor, generator, UPS loading, utility trip, inverter transfer, and battery discharge test should be completed for each component and the system.

f. Possible failures and corrective actions. For general assistance in resolving equipment failures of the UPS, tables 4-1 to 4-7 may be referenced. Specific troubleshooting guides of equipment are provided by the manufacturer.

Table 4-1. Circuit breaker corrective action

Circuit Breaker Problem	**Areas to Check**
Breakers will not close/trip	Mechanical alignment/ Interlocks Relay and protective device settings and operation
Breaker trips inadvertently	Ground on cable or system Relay and protective device settings and operation System overload

4-5. Test equipment

The amount of test equipment available should be appropriate to the amount of local use and should meet safety requirements. The user in some cases may have had some control over the amount of diagnostic and monitoring equipment, plus the special tools specified for UPS systems. In other cases, off-the-shelf equipment might have been installed. The maintenance personnel may be primarily electrically oriented. Such personnel may have had some training on UPS systems maintenance at one time. In some cases, highly qualified electronically oriented technicians may be available because of the need to service computer equipment. Because of the variations in UPS equipment and maintenance capability, a hard and fast list of recommended tools and test equipment cannot be given. Some general guidance is provided covering use of diagnostics, maintenance personnel, and ownership of equipment. Suggested checklists on maintenance test equipment are advisory only.

Table 4-2. Rectifier/battery charger corrective action

Rectifier/ Battery Charger	**Areas to Check**
No output voltage/ current	Input voltage/ breaker Rectifier (SCR) and rectifier fuse Input transformer Control board
Low output voltage	Dead input phase Rectifier (SCR) and rectifier fuse Voltage control settings or potential Control board
High output voltage	Input voltage high Voltage control settings or potential Control board
Output voltage not adjustable	Voltage control potential Control board
High output current	System overload/ short Current limit setting Control board
Low output current	Current limit setting Control board

Table 4-3. Battery corrective action

Battery	**Areas to Check**
Low battery voltage/ current/ capacity	Battery and cell connections Electrolyte level Cell voltage Cell condition, cleanliness, and age Float voltage/ current Battery room temperature Battery design versus actual load Battery/ system ground
Breaker trip	Battery / system short System overload

a. Use of maintenance personnel. Maintenance personnel should be able to recognize that a failure condition exists from observation of the display, alarm, diagnostics aids, and manufacturer's support. Simple failures such as blown fuses, defective fans, normal electrical-mechanical deficiencies, and electronic failures (i.e., printed circuit boards [PCB]) should not be beyond the repair or replacement capability of on-site maintenance personnel. Repair of the PCBs should be performed by the manufacturer.

b. Use of diagnostics. Display, alarm, and diagnostic equipment are generally provided in proportion to the cost and complexity of the UPS system. Whether personnel can repair equipment based on the diagnostics will depend on their training. All operating and maintenance personnel should be familiar with their display, alarm, and diagnostics aids to the extent that they indicate proper operation, the need for local repair, the need for manufacturer-provided repair or consultation, and the requirement to observe and record trends indicating a need for preventive maintenance.

Table 4-4. Inverter/static switch corrective action

Inverters/ Static Switch	**Areas to Check**
No output voltage/ current	Input voltage/ breaker SCR or diode Static switch Constant voltage transformer Control boards
Low output voltage	Input voltage System overload System frequency Control board
High/Low output frequency	Input voltage Alternate source Frequency control setting Control board
No transfer from Inverter A to Inverter B	Primary/Alternate source Static switch Synchronizing circuit Control board

Table 4-5. UPS system corrective action

System	**Areas to Check**
No output voltage/ current	Incoming voltage Circuit breakers System components
No transfer to Diesel generator	Diesel generator equipment/ breaker Transfer switch
Low/high output voltage/ current	Incoming voltage System components Battery sizing/ capacity System sizing/ capacity
Transfers not bumpless	Battery connection Static switch Control board
Inadequate UPS capacity	UPS sizing/ capacity Battery sizing/ capacity

c. Suggested lists of test equipment and accessories. A list of test accessories for an UPS battery is given in table 4-8, and a list of UPS module or power converter test equipment for a 500 kVA module is given in table 4-9. Special equipment may be available or may be rented, dependent upon the site's maintenance capabilities. Normal and safety equipment should already be available as a part of the electrical maintenance equipment. Manufacturer's equipment should be provided with the UPS equipment by the UPS manufacturer.

Table 4-6. Motor/engine corrective action

Engine Problem	**Areas to Check**
Will not start	Starter, Battery, and connections; Fuel system, level, pump, injectors, internal engine (valves, tappets, pistons), Ignition system (gas engines) Control system interlocks/permissives
Poor Performance / Will not handle load	Fuel System and cleanliness, injectors or carburetor, internal engine, control and ignition system, System kW requirements

Table 4-7. Generator corrective action

Generator Problem	**Areas to Check**
No Output Voltage / Current	Check Stator and Rotor Continuity, Fluid diode pack, voltage regulator, Control System and interlocks
Generator Breakers will not close	Control Circuitry operation, Auto/manual sync system, generator control system
Generator will not pick up load or stalls/trips	Engine fuel and control system, generator voltage regulator, generator control system, auto/manual sync system, protective device settings
Generators don’t share load	Paralleling control system
Main switchgear breaker won’t re-close on diesel generator powered system	Generator sync system, breaker sync check relay, breaker control circuitry.

Table 4-8. Suggested test accessory list for battery maintenance

Item	**Disposition**
Battery capacity test set	Special
Battery conductance/impedance tester	Special
Battery lifter	Special
Metering of dc (located on the rectifier charger)	Normal
Hydrometer set	Normal
Microohmmeter	Normal
Portable infrared temperature measuring device	Normal
Terminal protective grease	Normal
Thermometer set	Normal
Torque wrench	Normal
Chemical-resistant gloves	Safety
Goggles and face shield	Safety
Protective aprons or suits and shoes	Safety
Rubber matting	Safety

Table 4-9. Suggested test equipment list for troubleshooting an UPS module

Item	**Disposition**
Analog multimeter	Normal
Digital multimeter	Normal
Dual trace oscilloscope	Normal
Load bank	Normal
Phase rotation meter	Normal
Portable ammeter	Normal
Portable clamp-on current transformer	Normal
Portable infrared temperature measuring device	Normal
Built-in test equipment board	Manufacturer
Diagnostic printed-circuit board (PCB) and all related parts	Manufacturer
Extender cable kit	Manufacturer
Capacitor shorting device	Safety
Rubber matting	Safety